PATENT SPECIFICATION

(11) 1 246 858

DRAWINGS ATTACHED

1 246 858

(21) Application No. 3763/69 (22) Filed 23 Jan. 1969
(31) Convention Application No. 3 866 (32) Filed 23 Jan. 1968 in
(33) Japan (JA)
(45) Complete Specification published 22 Sept. 1971
(51) International Classification H 01 1 1/14
(52) Index at acceptance

H1K 211 217 225 271 287 288 306 312 341 34Y 383 384 386 38Y 391 424 43Y 441 454 459 463 469 470 483 486 491 518 51X 52Y 530 53X 578 579 581 593 60Y 611 615 619 61Y 630

(54) SEMICONDUCTOR DEVICE

(71) We, MITSUBISHI DENKI KABUSHIKI KAISHA, of No. 12, Marunouchi 2-chome, Chiyoda-ku, Tokyo, Japan, a Body Corporate organised and existing under the laws of Japan, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a semiconductor device having means for holding a wafer of semiconductive material including at least one P-N junction in place within the semiconductor device.

The conventional type of power semiconductor device, in most cases, comprises a wafer of semiconductive material having a layer of alloying and bonding metallic material disposed in non-rectifying contact with at least one of the main faces thereof and rigidly secured to a supporting plate made of a metallic material whose coefficient of thermal expansion approximates that of the semiconductive material, to avoid thermal fatigue of the semiconductive material. For example, with a wafer made of semiconductive silicon, the supporting plate could be formed of molybdenum, tungsten or the like and the alloying and bonding material, called a "hard solder", could be aluminium, a gold-boron alloy, gold-antimony alloy, silver-lead-antimony alloy, etc. in the form of foil. These hard solders are very different in coefficient of thermal expansion from the semiconductive material and therefore the latter material is subject to strain and cracking during the alloying and bonding operation. In order to prevent the occurrence of such strains and cracks, the material of the supporting plate has been selected to have an expansion characteristic approximating that of the semiconductive material.

To increase the capability and dielectric strength of semiconductor devices the semiconductive wafers are increased in radius and thickness. This increase in radius of the semiconductive wafer results in an increase in radius of the supporting plate because of the necessity of bonding the plate to the entire main face of the wafer. When the semiconductive wafer, the supporting plate, and the layer of hard solder interposed therebetween are alloy-bonded into a unitary structure, the wafer and plate flex and cause stresses to occur in the materials of the wafer and plate. If the semiconductive wafer is circular, the magnitude of its flexure is directly proportional to the square of its radius and inversely proportional to its thickness. On the other hand the stress developed in the semiconductive material due to the alloying and bonding operation is not only directly proportional to the flexure but increases with the radius and thickness of the semiconductive wafer. Thus it has been assumed that the shearing force on the peripheral portion of the circular wafer may amount to several times the average strain on that portion. The flexure of the semiconductor wafer as above described greatly affects the electric characteristics of the resulting semiconductor device and in particular of the P.N. junction formed in the wafer. In addition, repeated heat cycles of the device are likely to damage and/or break the semiconductive wafer during service.

Thus it will be appreciated that even if it is attempted to increase the diameter and thickness of a semicondutive wafer in order to increase the capability and dielectric strength thereof, it is difficult to produce an electrically and mechanically satisfactory semiconductor device in which the wafer is alloy-bonded to the supporting plate by a hard solder, unless there are provided means for suppressing the increased strain and stress developed in the wafer owing to the increase in diameter and thickness thereof. Supporting plate materials more closely ap-

proximating the coefficient of thermal expansion of the semiconductor material than the conventional plate materials are not readily commercially available. Therefore it is substantially impossible to produce semiconductor devices as just described industrially.

According to the invention there is provided a semiconductor device comprising a wafer of semiconductive material having two opposite substantially parallel main faces and at least one P-N junction formed therein, a respective thin contact layer of substantially uniform thickness disposed in ohmic contact with each of the main faces, and supporting means for the wafer which comprise two supporting plates of metallic material approximating in coefficient of thermal expansion the material of the wafer and having respective flat supporting surfaces substantially equal in diameter to each other and slidably engaged by the associated contact layers, and two conductive members which sandwich between them and are slidably engaged by the two supporting plates, each of said supporting plates having on its flat surfaces contacting the adjacent contact layer a thin layer of ductile material.

The invention will become more apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

Figure 1 is a graph plotting the reverse voltage-to-current characteristic of an exemplary semiconductor device embodying the invention compared with a prior art device;

Figure 2 is an exploded side elevational view, partly in section, of an exemplary semiconductor device embodying the invention; and

Figure 3 is a side elevational view, partly in section, of a modification of an assembly including the device of Figure 2.

In conventional semiconductor devices comprising a wafer of semiconductive material having two opposite main faces and a supporting plate brazed or soldered to one of the main wafer surfaces by a layer of so-called hard solder, the wafer and plate flex after the brazing operation as previously described. The flexure of the wafer and plate increase with increase in diameter.

As an example, a circular silicon wafer having a diameter of 38 mm, a thickness of 0.51 mm and a P-N junction formed therein had applied on one of the main face on aluminium foil equal in diameter to the wafer and having a thickness of 0.05 mm. Applied to the aluminium foil was a supporting plate of tungsten equal in diameter to the wafer and having a thickness of 2.0 mm. The assemblage thus formed was put in a graphite jig and heated at 700°C in a vacuum to be united into a unitary structure. After this heating operation the united wafer and plate flexed so that the exposed face of the plate became concave. Thus the centre of the exposed wafer face projected, its flexure amounting to approximately 25 microns.

It will be appreciated that the flexed semiconductive wafer had a considerable shearing force developed in the peripheral portion thereof. Also the flexure of the silicon wafer will affect the electric characteristics of the P-N junction formed therein and particularly cause an increase in leakage current in the reverse direction.

To show experimentally this increase in reverse leakage current, the peripheral edge of the wafer attached to the plate was sand-blasted so that a peripheral annulus 0.5 mm wide was cut away at an angle of approximately 40° to the main faces to form a bevelled surface on which the P-N junction was exposed. All the portion of the surface of the wafer was masked with an etchant resisting material except for the exposed edge of the P-N junction and the surface portion adjacent thereto. Then the wafer was etched in a mixture of nitric and hydrofluoric acid after which the reverse characteristic of the device was measured at 150°C.

The result of the measurement is illustrated at curve I in Figure 1, wherein the axis of abscissas represents a reverse voltage in volts applied across the P-N junction and the axis of ordinates represents the leakage current in milliamperes flowing through the P-N junction.

For comparison a silicon wafer identical to the wafer as above described had an aluminium layer deposited on one face thereof to a thickness of about 10 microns by evaporation followed by sintering at about 600°C. Then the wafer with the sintered aluminium layer was worked and measured in the manner above described. The result of measurement is illustrated at curve II in Figure 1. By comparing curve I with curve II, it will be appreciated that the conventional wafer and plate combination of curve I had a much greater reverse leakage current.

The compressive stress developed in the conventional silicon wafer above described was calculated on the basis of N. Klein's article entitled "Thermal Stresses and Fatigue in Silicon Power Rectifiers" in A.I.E.E., Communication and Electronics, Vol. 71 '1964) p. 208. It was found that the compressive stress average about 23,000 psi at −30°C.

Thus it is estimated that in a wafer having a diameter of 38 mm as in the above-mentioned example, the peripheral edge thereof will be subjected to a shearing force equal to two or three times the average compressive stress, which force exceeds the upper limit of the ultimate strength for silicon. The results of experiments indicated that

wafers of semiconductive materials having different impurities thermally diffused thereinto and attached to the associated supporting plates as previously described were locally broken at $-40°C$.

Figure 2 illustrates a preferred embodiment of the invention, comprising a semiconductor element 10 which comprises a wafer of any suitable semiconductive material. The wafer illustrated was in one specific case a disk of n type silicon having a diameter of 38 mm and a thickness of 0.5 mm it may have any other desired shape and dimensions. Gallium was diffused into one of the two opposite main faces of the wafer 12 to form a p type diffusion layer 14 defining a P-N junction 16 with the n type substrate 18. Phosphorus was strongly doped in the other main face of the wafer 12 to a surface concentration of approximately 1×10^{20} atoms per cubic centimeter to form an n^+ type diffusion layer 20 defining an N-N$^+$ junction 22 with the substrate 18. Impurity materials other than gallium and phosphorus may be used.

On the opposite main faces of the wafer 12, except for their outer peripheral zones, thin circular layers 24 and 26 of aluminium were deposited to a thickness of 5 to 10 microns by evaporation. After sintering the layers 24 and 26 are in ohmic contact with the main wafer faces respectively. A ring 28 of the same material as the wafer was disposed on the exposed surface of the p type diffusion layer 14, i.e. the peripheral zone of the main wafer face adjacent the P-N junction 16 not covered with aluminium, a ring shaped foil 30 of aluminium being interposed between the ring 28 and wafer 12. The assemblage thus prepared was heated to about 660°C to be formed into a unitary structure. In the specific embodiment illustrated the ring 28 was made of silicon and was 40 mm in outside diameter, 34 mm in inside diameter and 0.8 mm thick, and the aluminium foil 30 was 38 mm in outside diameter, 34 mm in inside diameter and 0.02 mm thick.

The periphery of the wafer 12 and the adjacent portion of the ring 28 are shaped into a frustum of a cone by a known technique, e.g. sand-blasting. The frustum tapers from the ring 28 to the wafer 12. A conventional etching process was used to render the shaped peripheral surface of the wafer 12 inactive. An annular deposit 32 of any suitable protective material e.g. a silicon varnish was applied to the edge of the wafer 12 and the adjacent portion of the silicon ring 28 to complete the semiconductor element 10, the aluminium layers 24 and 26 serving as an anode and a cathode electrode respectively, the semiconductor element 10 being a rectifier-diode.

Fitted into the ring 28 is a supporting plate 34 complementary in shape to and somewhat greater in axial dimension than the interior of the ring. The supporting plate 34 is provided on that surface engaging the ohmic contact 24 with a smooth thin layer 36 of any suitable ductile metallic material, preferably a material identical to that of the ohmic contact 24. The plate 34 is disposed in the ring 28 under pressure. In the example illustrated, the supporting plate 34 was a circular disk of tungsten having a diameter of 33.5 mm and a thickness of 1 mm with the opposite surfaces finished into substantially parallel planes.

Another supporting plate 38 similar to the plate 34 is disposed within the annular deposit 32 under pressure, having a smooth thin layer 40 of any suitable ductile metallic material engaging the ohmic contact 26. The material of the layer 40 is preferably identical to that of the ohmic contact 26. In the example illustrated, the supporting plate 38 was identical to the supporting plate 34.

The supporting plate 34 and 38 are aligned and are maintained in resilient engagement with the element 10 by suitable spring means (not illustrated in Figure 2). This measure permits each of the supporting plates 34 and 38 to slip relative to the element 10.

The components as above described are assembled in a structure such as shown in Figure 3, which comprises a seal block 50 at the cathode side of the element 10. The seal block 50 includes a hollow cylindrical member 52 of any suitable ceramic having a circumferential ridge 54 on its outer periphery, and a cylindrical member 56 of any suitable electrically conducting material, e.g. copper, for receiving the supporting plate 38.

The member 56 is provided on that side facing the supporting plate 38 with a recess 58 into which the plate 38 is snugly fitted. A cathode flange 58 of any suitable metal e.g. "Kovar" (Trade Mark) is brazed to the side of the cylindrical member 56 remote from the element 10 and to the adjacent end of the ceramic cylindrical member 52, e.g. by a silver solder 60. The ceramic member 52 also has a sealing flange 62 of "Kovar" brazed at the opposite end e.g. by a silver solder 60′.

A hollow cylindrical member 64 of any suitable electrically insulating material is fitted onto the cylindrical member 56 to position the element 10 within the hollow cylindrical member 52. To this end, the insulating cylindrical member 64 has an inside diameter sufficient to permit the element 10 to be snugly fitted into the member 64. The supporting plate 38 is fitted into the recess 58 after which the element 10 and supporting plate 34 are disposed on the plate 38 in the named order.

In the case of a semiconductor element

10 and associated components having dimensions previously specified, the recess 58 on the cathode member 56 had a diameter of 33.6 mm, a depth of 0.5 mm and a smooth flat bottom having brazed thereto a silver disc 32 mm in diameter and 0.2 mm thick. The silver disc had a surface roughness of approximately 5 microns or less. The insulating cylindrical member 64 had an inside diameter of 41 mm.

Disposed on the supporting plate 34 on the anode side of the element 10 is an electrically conductive plate 68 on which a metallic seal block 70 is disposed. The seal block 70 is in the form of a cylinder having a circumferential ridge and an anode flange 72 of S-shaped cross section brazed at one end to the outer shoulder of the ridge e.g. by a hard solder 62″ and secured at the other end to the free end of seal flange 62 by an argon arc weld metal 74.

Thus it will be appreciated that the semiconductor element 10 including a P-N junction is fully hermetically sealed from the atmosphere and is resiliently held between the seal blocks 50 and 70 by the spring action provided by the sealing flange 72 of S-shaped cross-section.

Also since the supporting plates 34 and 38 are held between the wafer 12 and the sealing members 56 and 70 by mechanical means rather than by brazing or soldering as previously employed, the problem of thermal fatigue occurring upon assembling the device is fully avoided. In addition, even if thermal expansion and contraction of different magnitudes occur in the materials of the sealing members 56 and 70 in operation, such expansion and contraction are absorbed by the slip along the interfaces of the wafer and supporting plates with the result that the flexure and shearing force occurring in the semiconductive material of the wafer are negligible. Thus, the wafer is effectively protected from thermal fatigue in operation.

However the pressure applied to the element 10 from the resilient flange 72 through the seal block 70 may be insufficient to ensure satisfactory operation of the semiconductor element 10. In order to ensure satisfactory operation, it is desirable to dispose a strong spring externally of the arrangement shown in Figure 3, to exert on the associated main face of the semiconductive wafer a pressure of 100 to 300 kg/cm². This measure ensures that each of the supporting plates is maintained in electrically and mechanically good contact with the adjacent ohmic contact.

Aluminium, which is of low elasticity and high ductility, forms the layers 24 and 26 serving as the ohmic contacts. Consequently the wafer 12 is not subject to any flexure or shearing force upon formation of such ohmic contacts. Thermal strains in the sealing members 56 and 70 are not directly transmitted to the wafer 12, because the supporting plates are formed of such as tungsten, or high elasticity and substantially approximating in coefficient of thermal expansion the material of the wafer in this case silicon.

It is further recalled that the semiconductor element 10 consists only of the wafer 12 and ring 28, made of similar materials. The wafer is thus effectively prevented from being contaminated with any dissimilar material during the etching operation. Such contamination has arisen from the previous practice of using dissimilar materials to form such wafer and ring. For example, wafers of semiconductive silicon have hitherto had rings of tungsten or molybdenum brazed or soldered thereto; during the etching operation tungsten or molybdenum has dissolved in the etching solution to contaminate the wafer with the result that the electrical characteristics of the finished semiconductor element were adversely affected.

In the examples illustrated, the supporting plates 34 and 38 were tungsten. In general they may be of any suitable metallic material substantially approximating silicon in coefficient of thermal expansion. Examples of such materials are molybdenum, tantalum, "Kovar" etc, for silicon wafers.

For germanium wafers, the supporting plates are preferably made of tungsten, molybdenum, tantalum or "Kovar".

In the embodiment disclosed herein both the supporting plates contact the adjacent faces of the wafer with circular areas having the same diameter. This measure contributes to uniformity of pressure applied to the respective faces of the wafer and normal thereto, and simplifies the components and aids exchangeability thereof.

The aluminium layer 36 or 40 serves to keep the plate 34 or 38 in intimate contact with the associated main face of the wafer to decrease the contact resistance therebetween while permitting sliding movement effected therebetween. If desired, the aluminium layer may be omitted.

Examples of other metals suitable for forming the abovementioned ohmic contacts 24 and 26 (and layers 36, 40) are gold, silver, and nickel. Any of these metals may be advantageously deposited or plated on the main wafer faces. Preferably the layers 36, 40 are of the same metal as the adjacent ohmic contacts.

While the invention has been described in terms of silicon diode including a P-N junction, it is to be understood that the invention is equally applicable to semiconductor diodes formed, for example, of germanium, III-V compounds or the like. It is also to be understood that the invention is equally

applicable to a wide variety of other semiconductor devices such as thyristors, transistors, etc.

WHAT WE CLAIM IS:—

1. A semiconductor device comprising a wafer of semiconductive material having two opposite substantially parallel main faces and at least one P-N junction formed therein, a respective thin contact layer of substantially uniform thickness disposed in ohmic contact with each of the main faces, and supporting means for the wafer which comprise two supporting plates of metallic material approximating in coefficient of thermal expansion the material of the wafer and having respective flat supporting surfaces substantially equal in diameter to each other and slidably engaged by the associated contact layers, and two conductive members which sandwich between and are slidably engaged by the two supporting plates, each of said supporting plates having on its flat surface contacting the adjacent contact layer a thin layer of ductile metal.

2. A semiconductor device according to claim 1 in which the contact layers are formed of aluminium, nickel, gold or silver and have a thickness of 10 microns or less.

3. A semiconductor device according to claim 1 or 2 in which at least one of the supporting plates is encircled by a reinforcing ring of substantially the same material as the wafer and fixed to the wafer on the outer periphery of that portion of the main wafer face contacting the supporting surface.

4. A semiconductor device according to any of claims 1 to 3, in which the supporting plates are formed of molybdenum, tunsten or tantalum.

5. A semiconductor device according to any of claims 1 to 4, in which the wafer is formed of silicon, germanium or a III-V compound.

6. A semiconductor device substantially as herein described and shown in the accompanying drawings.

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Printed for Her Majesty's Stationery Office by The Tweeddale Press Ltd., Berwick-upon-Tweed. 1971
Published at the Patent Office, 25 Southampton Buildings, London WC2A 1AY from which copies may be obtained.

1246858 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

FIG. 1.

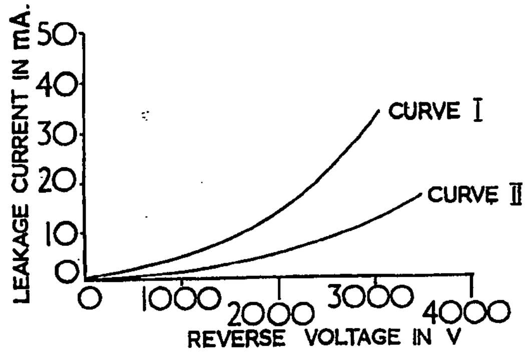

FIG. 2.

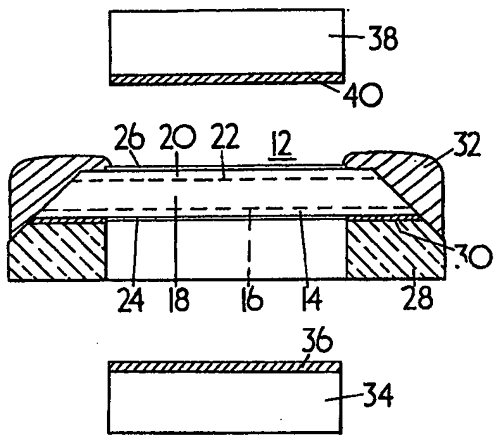

FIG. 3.